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Effect of Ground Water Sodium Chloride Attack on Reinforced Concrete Footings

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Abstract

In footings construction, it is very important to protect the reinforced concrete in direct contact with the soil from the ground water attack, especially if it is consisting of risky salt such as NaCl. One of the main objectives of this paper is to study the effect of ground water NaCl attack on the compressive strength and on steel reinforcement of footings, which is usually subjected to ground water. The experimental work consists of two main stages; first is preparing plain concrete and reinforced concrete for ordinary and high strength concrete and the second stage is finding the compressive strength and reduction in the weight of reinforcement (Corrosion) after curing the specimens in salty water of NaCl concentration 4000 mg/l. The important conclusions are the compressive strength of concrete decreases when the concrete is submerged with salty water (NaCl) with percentage decrease 51% for ordinary concrete (OC) and 38% for high strength concrete (HSC). Regarding the effect of concrete cover on reinforcement, the results show that the corrosion in steel reinforcement decreases when the concrete cover increases. Finally, use of high strength concrete and a suitable concrete cover are very useful in protecting the reinforced footings and in improving durability.

Keywords: *Ground water, chloride attack, footing durability, corrosion in steel*

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INTRODUCTION

In most areas of the world especially in Iraq, ground water represents a main problem to the concrete footings of buildings such as settlements and corrosion of reinforcement etc. Ground water in Iraq contains a large concentration of NaCl salt; for this reason, this paper conducted the effect of sodium chloride salt in ground water on the durability of reinforced concrete, which is in direct contact with salty ground water and ways to improve reinforced concrete durability.

Niville presented an overview on many researches dealing with the chloride attack of reinforced concrete [1]. The mechanism of chloride-induced corrosion in steel bars embedded in cement and the limitations of British Standards BS 8110: Part 1: 1985 and the approach of ACI code and other standards for the chloride content in the concrete were studied. The study also presented the influence of blended cements on corrosion and the factors influencing corrosion. The thickness of concrete cover to reinforcement and its importance in protecting steel bars of corrosion is presented which will be investigated in present study. In the concluding remarks, the author focuses on understanding the phenomena involved in corrosion of bars and the influencing factors on corrosion, which makes it possible to design successful structures, which will be exposed to chloride.

Pruckner and Gjørv investigated the effect of chloride content from different sources on concrete corrosivity [2]. They have tested the electrical resistivity and capacity of acids in concrete as an index of corrosivity by examining different quantities of $CaCl_2$, NaCl, and NaOH added to fresh mixtures with OPC (ordinary Portland cement) and 0.5 water/cement ratio. It was found that the NaCl as a chloride source gives a higher value of pH and electrolyte resistivity compared to $CaCl_2$ as chloride source.

Kelestemur and Yildizai investigated the rust in the steel reinforcement due to many percentages of NaCl and styrofoam replaced of 15% of the volume of aggregate in concrete [3]. Steel rust with 10% silica fume was also studied. The rates of rust were measured agreeing to the galvanic current method. The conclusions showed that the rust rate with styrofoam increased when the percent of sodium chloride increased and the rust rate decreased as the silica fume was used.

Silva improved awareness about appliances by chloride leading to depassivation of concrete reinforcement by investigating the steel surface condition and concrete-steel interface on the initiated rust and distribution of chloride along it at the depassivation time [4]. The conclusions showed that the condition of steel surface and the air voids present at the concrete-steel interface are known as main aspects inducing the potential grades along the surface of steel.

Roman *et al*. presented the galvanized steel bars, which is used to reinforce concrete touching the action ions of chloride [5]. Two types of cement were used which are Portland cement and Pozzolanic cement. The reinforced concrete was exposed to NaCl with immersion. The corrosion measurement and its existence with time were visualized. It was concluded that the bars' behavior depends on calcium aluminate content and its interfacing with the ions of chloride for both types of cement.

EXPERIMENTAL WORK

Materials and Specimens

Two main types of mixes are adopted in this study which are 1:2:4 ordinary concrete (OC) and 1:1.3:2.6 high strength concrete (HSC) with 10% silica fume by weight of cement and silica fume (CF) glenium water reducer added as 1 l for each 100 kg cement. SBR latex polymer is used in mixes except reference mixes. Polymer modifies concrete used in construction to have more durable concrete and improves physical and mechanical properties such as low porous concrete (less permeable concrete), increasing compressive and flexural strength, this polymer as well as silica fume is used to get a high strength concrete. Sulphate resisting cement is used in all mixes, coarse aggregate with 10 mm maximum size and sand as fine aggregate confirming zone 4 of IS Standards.. Used materials are specified as per Iraqi Standard Specifications for Construction Materials [6]. Three percentages of SBR polymer cement ratio (p/c) (0, 5, 10%) are adopted. To achieve the required specimens, cylindrical 75 mm in diameter×150 mm in height and 100 mm in diameter×200 mm in height molds are used for the unreinforced and reinforced samples respectively. The reference samples are cured in a drinking water with NaCl concentration of 4 mg/l (normal water) and other samples are cured in salty water with NaCl concentration of 4000 mg/l as a doubled value of the concentration of NaCl in ground water of Al-Najaf city in Iraq to help in speeding the oxidation process. To study the effect of salty water on the compressive strength of concrete, the reinforced specimen was tested to find compressive strength using ELE testing machine with 2000 kN capacity. To study the effect of salty water on the steel reinforcement, the reinforced specimens with 5/8 in in diameter bar in each specimen are used and submerged in salty water after hardened (24 h) and left for six months, then subjected to break by simple drill hammer and cleaning the reinforcement bar from rust and weighing it, the difference in weight of steel bar before use (original weight) and after it corrodes divided by original weight gives the reduction in weight for steel reinforcement, this reduction is named as corrosion, in this study.

Tests

Two main tests after the preparation of a total 72 specimens are made in this study. First is finding the compressive strength of unreinforced specimens, which is cured in drinking water and salty water. The average of each three concrete cylinders is adopted as a unique value of each case study parameters; this means that the sum of unreinforced specimens is 36. ELE testing machine of 2000 kN capacity is used in the concrete laboratory in Faculty of Engineering/ University of Kufa. The second main test is made on 36 reinforced specimens to find the reduction in weight of reinforcement (Corrosion %) by weighing the bars before use in and after six months of salty curing, then: % reduction (Corrosion %) = (original weight of

bar – weight of bar after test)/original weight. Figure 1 shows a samples of the specimens used in the study.

RESULTS AND DISCUSSION

Polymer Cement Ratio (P/c) and Compressive Strength (*f'c*) Relationship

The compressive strengths of the specimens without polymers and cured in drinking water (normal water) which are representing the reference values are listed in Table 1. For the 75 mm×150 mm specimens, the relationship between SBR polymer cement ratio (p/c) and compressive strength (*f'c*) of ordinary concrete (OC) and high strength concrete (HSC) for normal water and salty water curing is drawn in Figures 2 and 3. It can be seen that the compressive strength increases as p/c increases for both of OC and HSC. The figures also show that the compressive strength for salty water curing is less than that of normal water curing. The same behavior appeared for specimens of size 100 mm×200 mm as shown in Figures 4 and 5.

Effect of Salt (NaCl) Concentration on Compressive Strength (*f'c*)

The relationship between the concentration of salt (NaCl) in the curing water of OC and HSC for both 75 mm×150 mm and 100 mm×200 mm specimens with and without polymer is shown in Figures 6–9. Because of the large difference between NaCl concentration of normal water and salty water, x-axis is drawn as a logarithmic scale to represent this difference. For all specimens (without and with polymer, 0, 5 and 10% p/c); the compressive strength decreased when the concrete was cured in salty water. This case simulates the salty ground water attack on the concrete footing submerged in it. Higher the compressive strength of concrete footing can be given, more durable and resistance due to salt attack, it can be made.

Fig. 1: *Samples of Specimens.*

Table 1: *Reference Samples Results (Unreinforced).*

Sample Type	Sample Size	Compressive Strength (MPa)
Ordinary Concrete	75mm×150mm	24.3
High Strength Concrete	75mm×150mm	50.63
Ordinary Concrete	100mm×200mm	26.7
High Strength Concrete	100mm×200mm	51.3

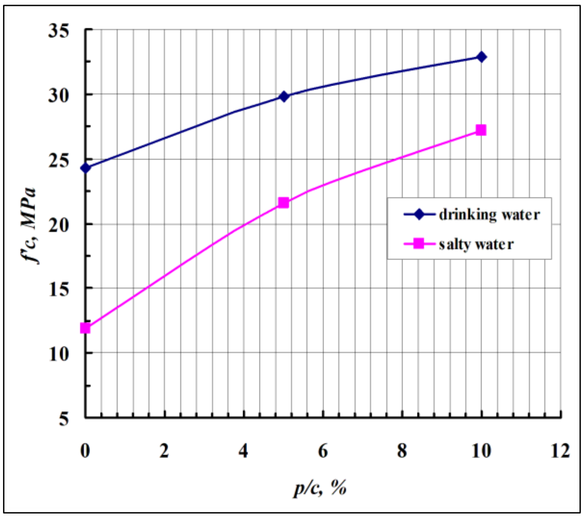

Fig. 2: *Polymer Cement Ratio and Concrete Compressive Strength Relationship for Ordinary Concrete, (75 mm×150 mm) Samples.*

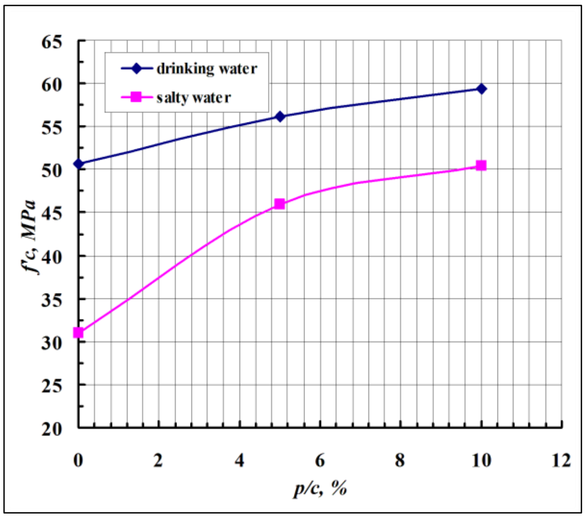

Fig. 3: *Polymer Cement Ratio and Concrete Compressive Strength Relationship for High Strength Concrete, (75 mm×150 mm) Samples.*

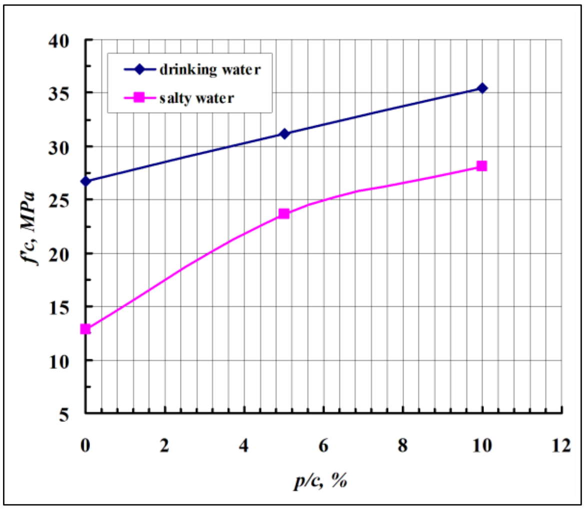

Fig. 4: *Polymer Cement Ratio and Concrete Compressive Strength Relationship for Ordinary Concrete, (100 mm×200 mm) Samples.*

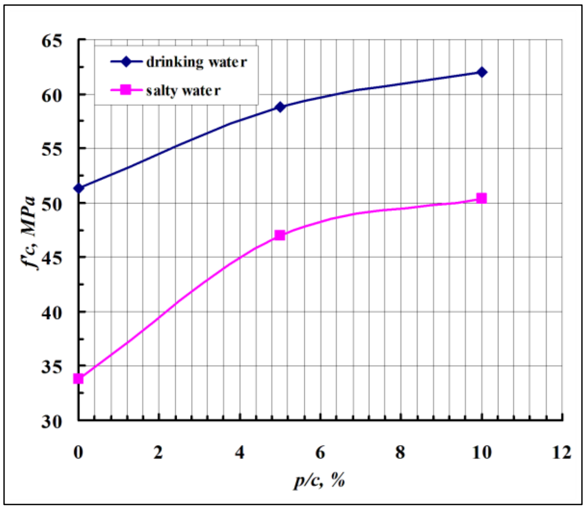

Fig. 5: *Polymer Cement Ratio and Concrete Compressive Strength Relationship for High Strength Concrete, (100 mm×200 mm) Samples.*

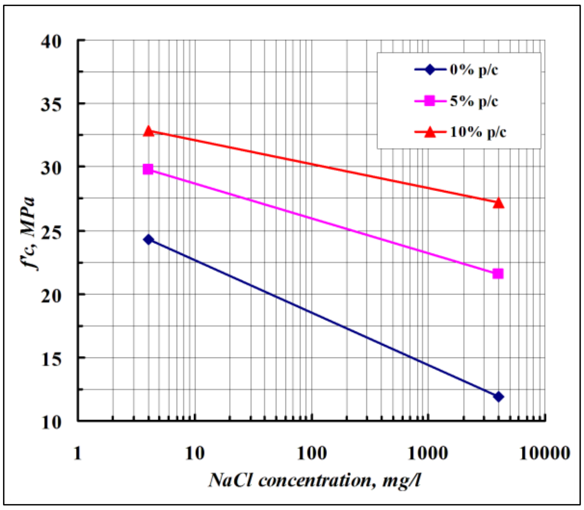

Fig. 6: *NaCl Concentration and Concrete Compressive Strength Relationship for Ordinary Concrete, (75 mm×150 mm) Samples.*

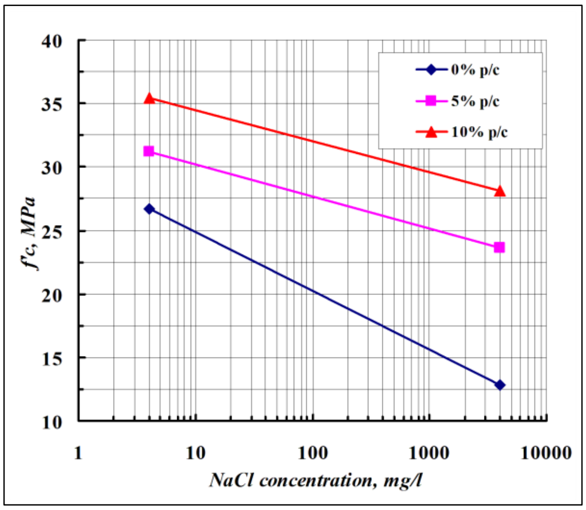

Fig. 7: *NaCl Concentration and Concrete Compressive Strength Relationship for Ordinary Concrete, (100 mm×200 mm) Samples.*

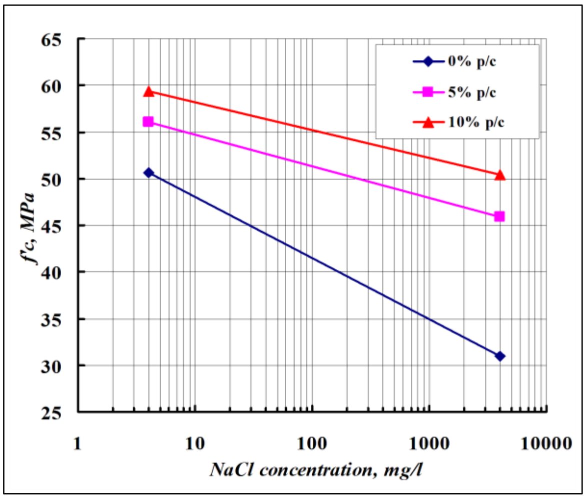

Fig. 8: *NaCl Concentration and Concrete Compressive Strength Relationship for High Strength Concrete, (75 mm×150 mm) Samples.*

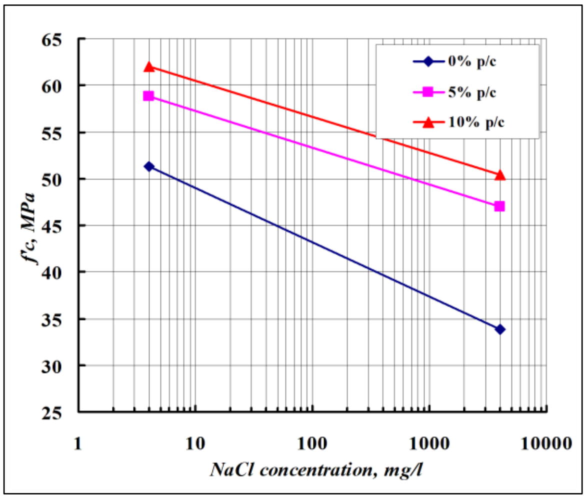

Fig. 9: *NaCl Concentration and Concrete Compressive Strength Relationship for High Strength Concrete, (100 mm×200 mm) Samples.*

Effect of Salt (NaCl) Concentration on Corrosion in Steel Reinforcement

The corrosion in steel reinforcement of reinforced specimens for ordinary concrete (OC) and high strength concrete (HSC) reinforced for both sample sizes are listed in Table 2. It can be seen that for all specimen without and with polymer, the corrosion in steel reinforcement decreases when the strength of concrete increases. The relationship is clearly shown in Figures 10 and 11, it can be seen that when the compressive strength increases, the corrosion decreases.

Table 2: *Results of Corrosion Due to NaCl (Reinforced).*

Sample Type	Sample Size	p/c (%)	f'c (MPa) of Salty Curing	Corrosion (%)
Ordinary Concrete	75mm × 150mm	0	11.87	8.55
		5	21.57	6.8
		10	27.2	5.3
High Strength Concrete	75mm × 150mm	0	31	5.8
		5	45.9	3.2
		10	50.4	2.8
Ordinary Concrete	100mm × 200mm	0	12.83	7.2
		5	23.64	6
		10	28.1	5.1
High Strength Concrete	100mm × 200mm	0	33.8	5.3
		5	47	2.6
		10	50.36	2.3

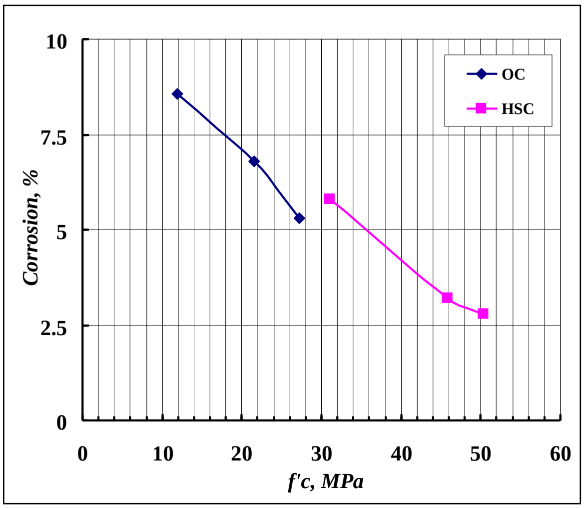

Fig. 10: *Compressive Strength and Corrosion in Steel Reinforcement Relationship, (75 mm×150 mm) Samples.*

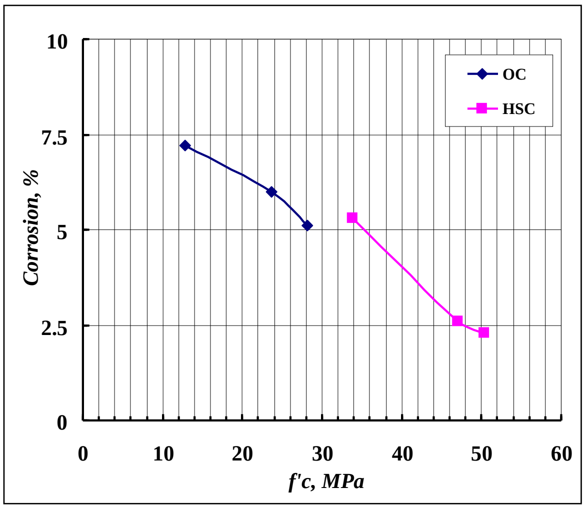

Fig. 11: *Compressive Strength and Corrosion in Steel Reinforcement Relationship, (100 mm×200 mm) Samples.*

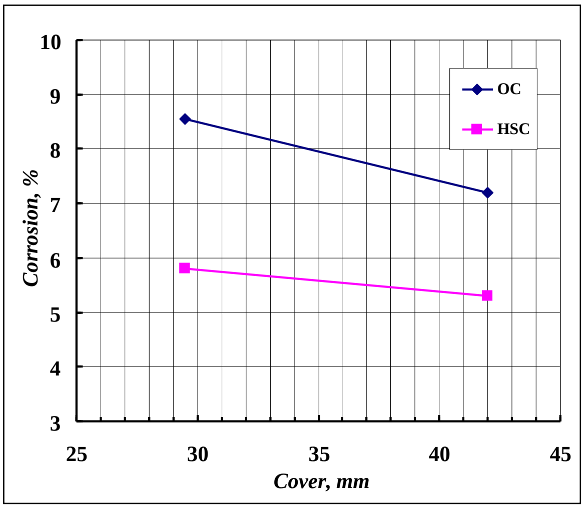

Fig. 12: *Cover Corrosion in Steel Reinforcement Relationship for 0% Polymer.*

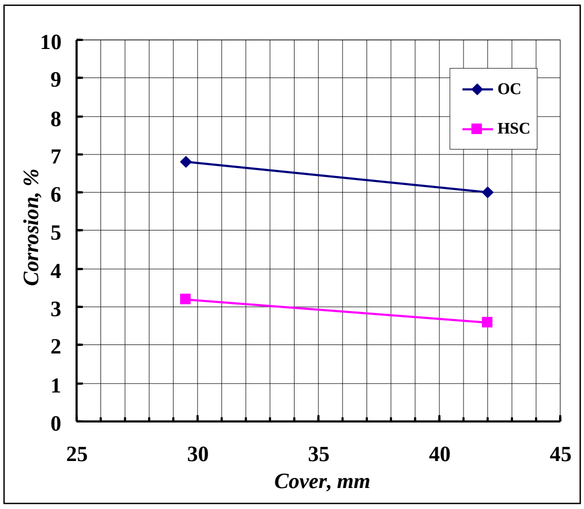

Fig. 13: *Cover and Corrosion in Steel Reinforcement Relationship for 5% Polymer.*

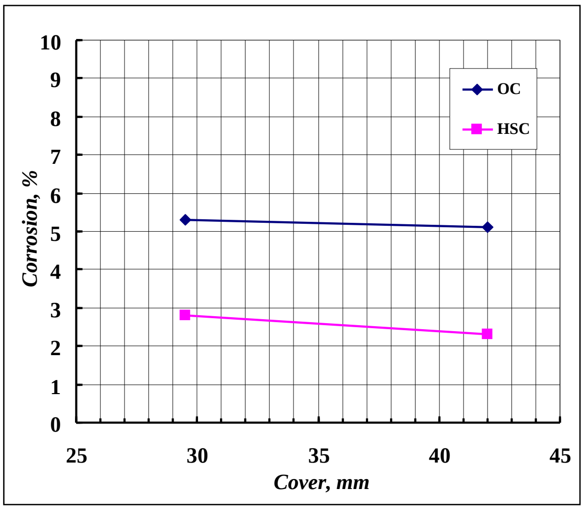

Fig. 14: *Cover and Corrosion in Steel Reinforcement Relationship for 10% Polymer.*

Effect Concrete Cover on Corrosion in Steel Reinforcement

The main purpose of using two sizes of specimens is to investigate the effect of concrete cover on the corrosion in steel reinforcement, which is possible to take place when the salty ground water attacks the concrete footing. For the specimens 75 mm×150 mm, the concrete cover can be calculated as (75 mm/2–16 mm/2 = 29.5 mm) and for the specimens 100 mm×200 mm, it can be calculated as (100 mm/2–16 mm/2 = 42 mm). Figures 12–14 show the relationship between the concrete cover and the corrosion in reinforcement for specimens without and with polymer. It can be seen that the corrosion decreases when the concrete cover increases, so, the reinforcement can be protected from salty water by the use of a suitable larger concrete cover.

CONCLUSIONS

This paper conducted an experimental study dealing with the effect of NaCl attack on the reinforced concrete represented by concrete of footings, which is in direct contact of ground and sometimes below water table. Two main types of mixes were prepared, which were 1:2:4 ordinary concrete (OC) and 1:1.3:2.6 high strength concrete (HSC) with 10% silica fume by weight with SBR latex polymer and silica fume. Reference specimens were cured in normal water (drinking water) for 28 days and in salty water for 6 months and then tested to study effect on the compressive strength of concrete and corrosion in steel reinforcement.

The experimental work results showed the following main conclusions:

1. The compressive strength of concrete increases when the polymer-cement ratio (p/c%) increases from 0 to 10% for both specimens, cured in normal water and salty water.
2. The compressive strength of concrete decrease when the concrete is submerged with salty water (NaCl) with percentage reduction (with respect to normal water submergence) 51% for ordinary concrete (OC) and 38% for high strength concrete (HSC).
3. The percent reduction in steel reinforcement weight (corrosion %) for the specimens 75 mm in diameter×150 mm in height reaches 5.3% for OC and 2.8% for HSC at the maximum compressive strength (p/c=10%) and reaches 8.5% for OC and 5.8% for HSC at the minimum compressive strength (p/c=0%). This means that when the compressive strength increases, the corrosion decreases, and the effect of NaCl attack on reinforcement corrosion is less.
4. For all percentages of p/c used for both OC and HSC, the corrosion in steel reinforcement decreases when the concrete cover increases which is studied by use of two sizes of molds (75 and 100 mm) diameters such as when the concrete cover increases from 29.5 to 42 mm the corrosion decreases by 15.5% at minimum compressive strength (p/c=0%) and 3.7% at maximum compressive strength (p/c=10%) for ordinary concrete (OC). For high strength concrete (HSC) the increase in concrete cover reduces the corrosion 8.6 and 17.8% for p/c=0 and 10% respectively.
5. To reduce the effect of NaCl attack on the reinforced concrete footing it can use high strength concrete (HSC) with SBR polymer and silica fume up to 10% by the weight of cement to get more durable reinforced concrete footing.

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